

Soft Electromagnetic Radiations from Relativistic Heavy Ion Collisions ¹

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I. Introduction

Photons and dileptons have long been considered as excellent probes of quark-gluon plasma (QGP) expected to be formed in relativistic heavy ion collisions. However, while evaluating these type of signals, the immediate interests were to study quasi-particle scattering in dense matter. In contrast, little has been done to account for the radiative or bremsstrahlung contributions to photons and dileptons from these quasi-particles. As will be shown these contributions are dominant as long as the energy remains below 1 GeV. It has also been argued that the system formed in relativistic heavy ion collisions undergoes rapid transverse expansion during the latter stages of the collision. Since low energy photons/dileptons are produced mostly from the late stage, they will be affected by the collective transverse flow. Therefore, one can get idea about the flow by studying low energy photons and dileptons. We apply soft photon approximation (SPA) to evaluate soft photons and dileptons from quark matter as well as hadronic matter. The estimations of soft electromagnetic radiations that exist in the literature have certain discrepancies (see Ref. [1] for details) which we have tried to correct in our calculations.

II. Formulation

The emission of soft photons (real or virtual) occurs from external lines in any process and the probability for such emission is given by the classical result [2]. The emission of photon from the interior of the scattering vertex is neglected because in the limit of very low energy of the emitted photon, its contribution is very low. The cross-section for the emission of soft real photon produced from a process $ab \rightarrow cd\gamma$ is given by [3] is given by

$$q_0 \frac{d\sigma^\gamma}{d^3q} = \frac{\alpha}{4\pi^2} \frac{\hat{\sigma}(s)}{q_0^2} \quad (1)$$

and for the emission of a soft dilepton we have

$$\frac{d\sigma^{e^+e^-}}{dM^2 d^2M_T dy} = \frac{\alpha}{12\pi^3 M^2} \frac{\hat{\sigma}(s)}{q_0^2} \quad (2)$$

¹Based on the talk presented by Pradip Kumar Roy in ICPA'QGP-1997, Jaipur, India.

Using kinetic theory we can write down the rate of production of soft photons from a system at temperature T as

$$E_\gamma \frac{dN^\gamma}{d^4x d^3q} = \frac{T^6 g_{ab}}{16\pi^4} \int_{z_{\min}}^{\infty} dz \frac{\lambda(z^2 T^2, m_a^2, m_b^2)}{T^4} \times \Phi(s, s_2, m_a^2, m_b^2) K_1(z) \left(q_0 \frac{d\sigma_{ab}^\gamma}{d^3q} \right), \quad (3)$$

where $z_{\min} = (m_a + m_b)/T$, $z = \sqrt{s}/T$, and $g_{ab} = N_a N_b (2s_a + 1)(2s_b + 1)$ is the colour and spin degeneracy appropriate for the collisions. Similarly we can obtain the rate for soft dilepton emission. Here we note that $\hat{\sigma}(s)$ consists of two parts- electromagnetic and strong or elastic. To evaluate the elastic cross-section in QGP sector we follow the prescription of Ref. [4]. In the hadronic sector we assume a model Lagrangian [5] for the calculation of strong cross-section.

Once the rates are obtained one can apply it for an evolving system to get

$$\frac{dN}{d^2q_T dy} = \int \tau d\tau r dr d\phi d\eta \left[f_Q q_0 \frac{dN^q}{d^4x d^3q} + (1 - f_Q) q_0 \frac{dN^\pi}{d^4x d^3q} \right] \quad (4)$$

where $f_Q(\tau)$ gives the fraction of the quark-matter[6] in the system.

III. Results

We calculate the transverse momentum distribution of soft photons and dileptons for a system undergoing transverse expansion. For this we will assume that initially a thermalised and chemically equilibrated QGP is formed in Pb-Pb collisions at proper time $\tau_i = 1$ fm/c [7]. Cooling due to expansion leads to first order phase transition at $T = 160$ MeV. When the conversion to hadronic matter is complete a pure hadron phase is realised which then freezes-out at $T = 140$ MeV. The complete dominance of soft photon multiplicity in the region of $0.1 < p_T(\text{GeV}) < 1.0$ is seen from fig. (1).

The result for transverse mass distribution for the low mass dileptons at RHIC energies is shown in fig. (2). We see that the pion driven processes dominate the yield at lower M_T . However at larger M_T , the contributions of quark and pion driven processes are almost same. This is a reflection of larger temperature in the quark phase, and a larger effect of transverse flow during the hadronic phase. However, the invariant mass spectrum does not show up this type of feature. Thus we see complete dominance of bremsstrahlung dileptons in the low mass region. Similar characteristics have been observed at SPS and LHC energies [8].

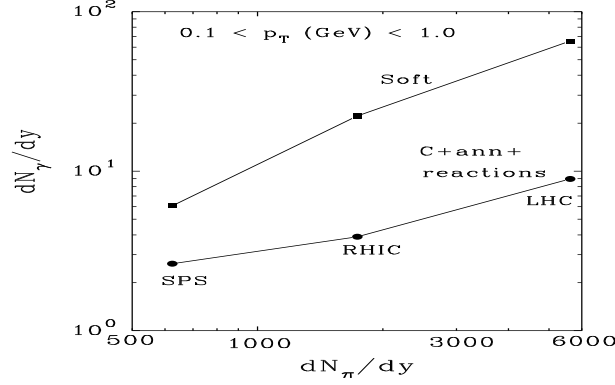


Figure 1: Soft photons vs. photons from Compton plus annihilation processes from the QGP and hadronic reactions at SPS, RHIC, and LHC energies from central collision of two lead nuclei.

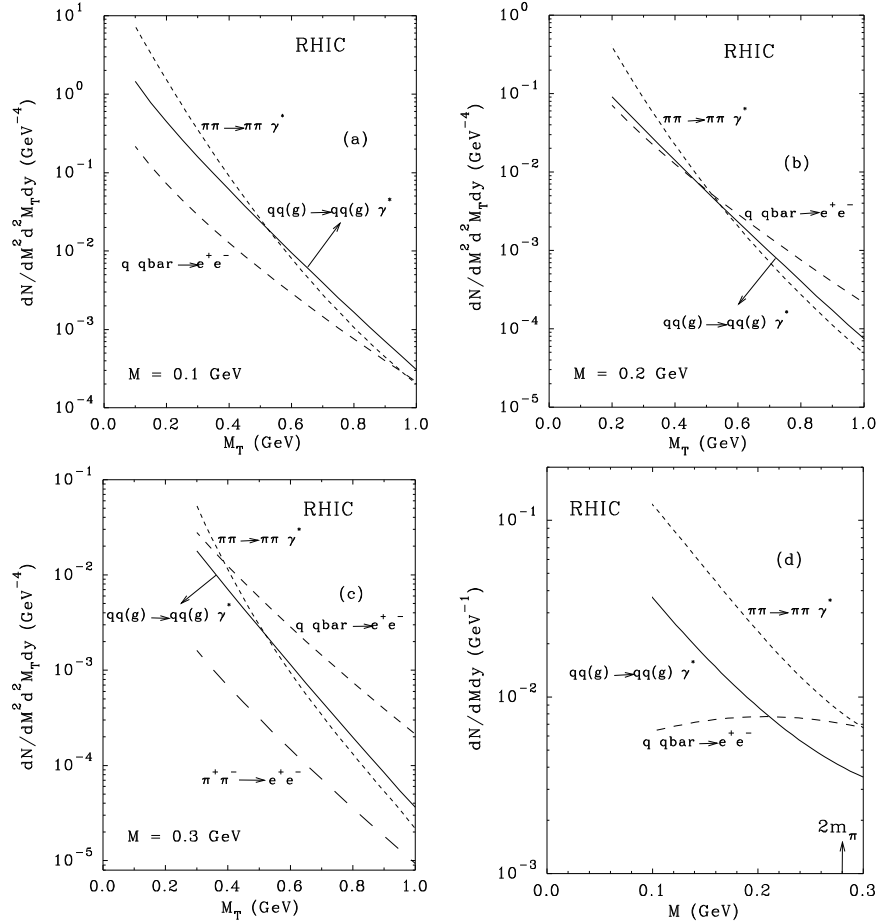


Figure 2(a–d): The transverse mass distribution of low mass dielectrons at RHIC energies including bremsstrahlung process and annihilation process in the quark matter and the hadronic matter. We give the results for invariant mass M equal to 0.1 GeV (a), 0.2 GeV (b), and 0.3 GeV (c) respectively. The invariant mass distribution of low mass dielectrons are also shown (d).

IV. Conclusion

We have calculated the transverse momentum distributions of photons and dileptons within a soft photon approximation at SPS, RHIC and LHC energies. We find that the formation of such a system may be characterised by an “intense glow” of soft electromagnetic radiations whose feature sensitively depends on the last stage of evolution once we remove the background of decay photons and dileptons and thus holds out the promise that soft electromagnetic radiations may be utilised as chronicles of final moments of relativistic heavy ion collisions.

We have kept our discussions limited to photon energies of more than 100 MeV in the hope that Landau-Pomeranchuk-Migdal suppression there may not be substantial. However, a qualitative argument [9] shows that LPM suppression is only marginal in the hadronic sector. Also in the quark sector this suppression may not be quite severe, though may not be as justified as pion driven processes in the energy region considered here.

This talk is an abridged version of Ref. [8].

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